AUDITORY POWERS OF THE CATOCALA MOTHS; AN EXPERIMENTAL FIELD STUDY.[1]

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HISTORICAL RESUMÉ.

Near the close of the nineteenth century, Romanes ('91) wrote: "Among insects organs of hearing certainly occur, at least in some, although the experiments of Sir John Lubbock appear to show that ants are deaf. The evidence that some insects are able to hear is not only morphological, but also physiological, because it is only on the supposition that they do that the fact of stridulation and other sexual sounds being made by certain insects can be explained, and Brunelli found that when he separated a female grasshopper from the male by a distance of several meters, the male began to stridulate in order to inform her of his position, upon which the female approached him. I have myself published observations proving the occurrence of a sense of hearing among the Lepidoptera."

The tone of three fourths of the above paragraph is characteristic of practically all of the early works upon the auditory powers of insects. Those men were convinced that insects hear; not because they had experimentally demonstrated it, but for morphological reasons, and because many kinds of insects can produce sounds. They believed that an insect would not be endowed with the power of producing sounds unless the other members of the species could hear. At first in the Orthoptera and later in other groups of insects, peculiar organs were found; consisting essentially of vibratory hairs attached to certain cells that seem to be sensory in nature. In some cases these hairs are in cavities and in others they are not. Such was the nature of the work of Siebold ('44), Leydig ('55), Henson ('66), Lee ('83, '85), Graber ('75, '82), Weinland ('91), Adelung ('92) and others. As late as 1905 Radl expressed the following thought. No matter

[1] For the identification of the species and for the experimental work on *C. unijuga*, E. Schwarz alone is responsible; the field work was performed jointly; for the planning of the work, for the historical resume and for the method of treatment, C. H. Turner is solely responsible.

how often in recent years doubt has arisen as to the ability of insects to hear, it has been largely maintained that they possess an auditory sense, and for the following two reasons: (1) the ability of many insects to produce sounds as a part of their normal behavior; (2) the possession by insects of organs which structurally seem fitted to act as receptors of sound waves.

Students interested in the morphological method of investigating this question will find the paper by Radl ('05) intensely interesting. After epitomizing the work by Lee ('83, '85), by Graber ('82), and by Weinland ('91), he states that, on a priori grounds, he doubted the assumptions of Graber; but that certain experiments had convinced him that insects have a crude auditory sense. In support of his contention, he offers the following reasons.

1. Graber is inaccurate when he claims that the chordotonal organs are located rigidly between two immovable parts of the body; for the proximal end is attached to an indifferent part of the body, while the distal end is in close proximity to one or more muscles.

2. The chordotonal organ cannot function like a string attuned to a certain pitch; because it expands and contracts.

3. All of the chordotonal organs examined are attached at each end to a chitinous framework and the nerve penetrates from the side.

4. The chordotonal organs resemble somewhat those muscles which occur especially in the limbs of the Arthropoda—muscles which terminate in long tendons.

5. No chordotonal organ is found in either the Myriapoda or the Arachnida.

6. Chordotonal organs are found in some insects for which a sense of hearing could have no significance. They are well developed in caterpillars; even in those of the Tortricidæ, which spend the entire larvel period inside of some fruit. They are also well developed in the internal parasites of certain insects.

7. All attempts to determine experimentally that insects react to pure and simple tones have yielded negative results: however, it is comparatively easy to evoke responses of insects to shrill noises, such as the voice of a cricket or the screech produced by

drawing a file across the edge of an iron or a glass plate. This is not a tactile reaction.

8. There is no evidence that noise, as such, causes the orientation of insects. The sounds produced by insects are more an outburst of inner feeling than an attempt to entice the female by the male.

9. The outcome of the whole matter is that there is an auditory sense in insects; but, it is on a much lower plane of development than that of the vertebrates. Its anatomical and physiological antecedents are to be found, not in the tactile organs and contact activities; but, anatomically in sense organs which register muscle activities and physiologically in general sensation (Gemeingefuhlen). The auditory sense of insects is a highly refined muscular sense.

Although the work of the early investigators was largely, often entirely, morphological, it must not be concluded that no experimental work has been done on the auditory powers of insects and their near kin. Such experiments have been performed in several groups of insects; but the results are inharmonious. Buttel-Reepen ('00) and De Fraviere believe that bees can hear. Buttel-Reepen's statement is based upon his observation that bees respond in a definite manner to the sounds of their own kind.

Huber ('10) and Forel ('03) interpret their experiments to mean that ants cannot hear. Lubbock's experiments likewise yielded negative results; yet, in spite of this, he was unwilling to admit that ants, wasps and bees cannot hear. Weld ('99) thinks he has experimentally demonstrated that ants can hear. Fielde and Parker ('04) interpret their experiments to mean that ants do not respond to sound vibrations as such. C. H. Turner ('07) is equally positive that his experiments demonstrate that ants can hear. At one time Wheeler believed, not only that ants can hear; but that they communicate by means of sounds; but, after the appearance of the paper by Fielde and Parker, he ('10) asserts that there is not sufficient evidence to warrant the assumption that ants can hear.

E. A. Andrews ('11) is convinced that termites hear. He writes: "In a community suspended from the ceiling by a copper

wire and represented by many thousands on a moist block of artificial stone which they got to from the nest by means of a long stick as bridge, it was first observed by Mr. Middleton that the noise of thunder and of blasting rocks was followed by a quick and very remarkable departure of almost all of the termites towards the nest. The blocks of stone weighed some sixteen pounds each and rested in a large pan of water on a firm wall of stone, so that it seemed likely that the concussion of the air came to the termites directly and not as a tremor of the stones they were clustered on. The same precipitous flight of the multitude of termites from these stones to the nest along the bridge was brought about by dropping a board upon the concrete floor with a loud crash. Even the clapping of hands, which probably shook the stone foundation but imperceptibly, served to drive the termites back to the nest. . . . Attempts to influence the termites by blowing horns of various pitches near them failed though considerable disturbance of the air was produced."

Montgomery ('10), after reviewing all that had been written on the auditory powers of spiders, concludes that spiders are deaf.

The above is not an exhaustive discussion of the published research work on the auditory powers of insects other than the Lepidoptera; yet, we trust it is sufficient to show the inharmoniousness of the results of different investigators.

To the best of our knowledge, the first published results of experiments upon the auditory powers of butterflies and moths is an article by Romanes ('76) which appeared about thirty-six years ago. The portion referring to the Lepidoptera is so short that we quote it in full. "It seems worth while to add a few words with respect to the sense of hearing in insects. So far as I am aware, the occurrence of such a sense in this class has never been actually proved. Although on *a priori* grounds there can scarcely be any doubt concerning the fact of some insects being able to hear; seeing that in so many species stridulation and other sounds are made during the season of courtship. In the case of moths, however, I believe that sounds are never emitted—except, of course, the death's head moth.[1] It therefore becomes inter-

[1] Romanes was mistaken when he asserted that the death's head moth is the only Lepidopteran than produces sounds; for the literature contains records of

esting to observe that an auditory sense is certainly present in these insects. Several kinds of moths have the habit of gently, though very rapidly, vibrating their wings, while they themselves are at rest on a flower or other surface. If, while this vibrating movement of the wings is going on, the observer makes a sudden shrill note with a violin, or fife, etc., the vibrating movement immediately ceases, and sometimes the whole body of the insect gives a sudden start. These marked indications of hearing I found invariably to follow a note with a high pitch, but not a note with a low one."

Heinrich ('09) remarks that collectors using a net to capture *Limenitis populi* and *Catocala fraxini* have observed that the insects often take flight before a collector is near enough to capture them. Accordingly to him no conclusive evidence has been published on the sense of hearing of insects, especially of the Lepidoptera. He noticed a *Laurentia suffumata* alight in a concert pavilion and remain quietly while the brass band played three selections, one of which was Wagner's Götterdammerung. He also noticed that certain Lepidoptera were more easily approached at twilight than when the sun was shining brightly, and he could not understand why this should be true if they were warned by a sense of hearing. He is convinced that, in all of these cases, it is vision, not audition, that warns butterflies and moths of the approach of man.

Hamann ('09) was led to investigate this subject by the remarks of collectors that butterflies and moths undoubtedly hear. One collector remarked that the noise caused by removing the cork from the cyanide bottle often caused these insects to fly. To this Haman replies that since the net is usually placed beneath the insect before the cork is removed it is probable that the sight of the net caused the flight. To test the matter, the following experiments were performed by him. (1) He approached a tree in such a manner as to be invisible to an *Apatura iris* L. resting thereon, and struck the tree with the bamboo handle of his

several species of Lepidoptera that emit sounds. Indeed, scarcely had his article appeared before several of his contemporaries published, in *Nature*, protests in which were cited several examples of sound-producing Lepidoptera. Recently Omensetter ('12) and Stephan ('12) have described several sound-producing forms of butterflies and moths.

collecting net. To this the insect made no response; but, as soon as the net approached it took flight. (2) a repetition of the experiment with *Vanessa* yielded similar results. (3) He noticed that certain Catocalas, which were not disturbed by the noise of a passing automobile, flew upon the approach of man. These experiments convinced him that butterflies and moths cannot hear.

Deegener's work ('09) is morphological. Between the thorax and the abdomen, on the ventral side of the body of all species of Nocturidæ, there is a depression containing chitinous structures and hairs which are connected with what seem to be sensory cells. A careful examination of this organ in *Pseudophia lunaris* convinced Deegan that it is probably an auditory organ.

Rothke ('09) confined a *Limenitis artemis* in a cage which he placed on the top of a pedestal two feet high. The sides and back of this cage were constructed of wood; but the front was covered with wire fly netting. At nine P.M., while the front of the cage was illuminated by means of a kerosene lamp, Rothke stepped to one side and made a slight noise. To this the insect made no response. The investigator then tapped rapidly and sharply upon the floor with a leather slipper. Although the jar was not sufficient to shake the stand upon which the cage rested, and although the investigator could not be seen by the insect, yet it slowly raised its wings until they met above its back and then lowered them again. Several repetitions of this experiment yielded identical results. During the intervals between the experiments the creature remained immobile. After the moth had been quiet for one quarter of an hour, Rothke rapped upon the table with a tumbler. Immediately the insect flapped its wings. About midday he discovered a specimen of *Catocala unijuga* resting quietly, about six feet from the ground, upon a pine tree one and a half feet in diameter. He picked up a stone about fifteen centimeters in diameter and threw it against the tree-trunk. Although the moth could not see the stone and although the blow was too slight to jar such a large tree, yet the moth flew away. Rothke is convinced that butterflies and moths can hear.

Observations made upon *Catocala pacta* L. convinced Richter

('09) that the crackling of twigs under his feet and even the slight noise made by removing the cork from his collecting bottle disturbed this moth. In another article, the same investigator ('10) has made a comparative study of the auditory powers of day-flying and night-flying Lepidoptera. He investigated the day-flyers; *Apatura* sp., *Vanessa* sp., *Limenitis populi* L., and *Sat. alcyone* Schiff. He found that species of *Apatura* and of *Vanessa* made no responses to sound so long as no visible object disturbed them. During a severe storm, he noticed a number of *Sat. alcyone* perching on a limb. Neither whistling, nor the clapping of hands, nor shaking of the limb had any effect on them: but, as soon as the hand of the collector approached them, they flew. A *Vanessa antiopa*, resting on a telegraph pole, was not disturbed by the shrill whistle and the rumbling noise of a passing train. In studying *Catocala fraxini* L., a night-flying moth, he noticed that it made no responses to the noises made by wagons, automobiles and the bells of a ferry; but that it responded readily to slight, high-pitched, sounds. He argues that the failure of this moth to respond to the sounds made by wagons and such things is because such sounds have no life significance for the moth. On the other hand, the ready response to the other sounds mentioned is due to their similarity to sounds made by field-mice, bats and owls—sounds which for the moth have a pronounced life significance. Partly influenced by the knowledge that Geegener had discovered chordotonal organs in the Noctuidæ and more so by the observations just described, Richter is convinced that day-flying Lepidoptera are warned by visual and night-flying forms by auditory stimuli.

For years Rober ('10) has raised *Acerontia atropos* L. from pupae. Late one evening a female emerged and, before her wings were fully dried, a male emerged in the cage. In order to separate the two, the female was removed to a cage in the bottom of which there was a crack as wide as one's finger. These cages were three meters apart. In the morning the female, which had escaped from confinement, was found perched on the cage containing the male. A person who slept in the room with these two moths asserts that, for a long time that evening, those moths emitted sounds. Rober concludes that these were love calls and that the

moths mutually heard. In face of the well known fact that the sense of smell is well developed in butterflies and moths, the evidence just cited does not appear to be conclusive.

Is it possible for anyone to read the above historical resume and not be convinced that there is need for much exact experimentation upon the auditory powers of insects? Evidently the last word has not been spoken.

Description and Discussion of Experiments.

Reading Stephan's ('12) recent articles on sound producing butterflies and moths induced in us the same thought that influenced the opinions of many of the early investigators; namely, animals that produce sounds as a part of their normal behavior can probably hear. We decided to make some crucial experiments. The Catocala moths were selected for the following reasons: (1) one of us is so well acquainted with the taxonomy of the group that it is easy to identify species afield; (2) the habit these moths have of resting during the day on some tree trunk and, when disturbed, flying to a nearby tree trunk renders them ideal material for field experiments.

Preliminary Observations.

Observations afield taught us that there are certain sounds to which these moths do not respond. A favorite haunt of the Catocala moths of this vicinity is a small stretch of wood through which a railroad passes. Moths resting on trees near the tract are not disturbed by the whistle, rumble and roar of passing trains. Near that same place there is a pleasure garden in which the sounds of a noisy piano are often heard. No responses to the strains of the piano were noticed.

These observations are in harmony with those of Heinrich ('09), Hamann ('09) and Richter ('09, '10).

Indoor Experiments on Catocala unijuga.

Three specimens freshly hatched from pupae were the subjects of these experiments. Each was kept in a separate room. Three times a day, for four days, the auditory powers of these moths was tested by whistling in a high key. Occasionally the moth was shielded from the draft of air caused by whistling;

TABLE I.

Catocala unijuga. SPECIMEN NUMBER 1.

Number of the Experiment.	Date.	Whistled, the Insect Shielded from the Air Currents.	Whistled, the Insect Not Shielded from the Air Currents.	Number of Times it Was Necessary to Whistle Before Response Was Received.
1	June 5, 1913, 10:00 A.M....	*N*		
2	" " " ...		*F*	1
3	" " " ...		*F*	1
4	" " " ...	*F*		4
5	" " " ...	*Q*		5
6	June 5, 1913, 10:30 A.M....		*F*	2
7	" " " ...	*Q*		6
8	" " " ...	*F*		3
9	" " " ...	*Q*		8
10	June 5, 1913, 6 P.M........	*F*		4
11	" " "	*Q*		3
12	" " "	*F*		6
13	" " "	*Q*		10
14	June 6, 1913, 9:00 A.M.....	*N*		
15	" " "	*Q*		4
16	" " "	*F*		2
17	" " "	*Q*		5
18	June 6, 1913, 11.00 A.M....	*F*		4
19	" " " ...	*Q*		10
20	" " " ...	*F*		4
21	" " " ...	*Q*		15
22	June 6, 1913, 6:00 P.M.....	*F*		8
23	" " "	*Q*		15
24	" " "	*F*		6
25	" " "	*Q*		19
26	June 7, 1913, 9:00 A.M.....	*F*		4
27	" " "	*Q*		10
28	" " "	*F*		4
29	" " "	*Q*		6
30	June 7, 1913, 10:00 A.M....	*F*		3
31	" " " ...	*Q*		8
32	" " " ...	*F*		3
33	" " " ...	*Q*		15
34	June 7, 1913, 7:00 P.M.....	*F*		6
35	" " "	*Q*		5
36	" " "	*F*		4
37	" " "	*Q*		6
38	June 8, 1913, 10:00 A.M....	*F*		2
39	" " " ...	*Q*		10
40	" " " ...	N_4		
41	" " " ...	*Q*		6
42	June 8, 1913, 10:30 A.M....	*N*		
43	" " " ...	*Q*		6
44	" " " ...	N_2		
45	" " " ...	*Q*		10
46	" " " ...	*F*		2
47	June 8, 1913, 6:00 P.M.....	*F*		4
48	" " "	*Q*		3
49	" " "	*F*		6
50	" " "	*Q*		10
51	" " "	*F*		13

Explanation of Tables I–III.

N indicates no response; *F* means that the moth flew; *Q* indicates that the insect waved its wings up and down or made some quivering movement.

Table II.

Catocala unijuga. Specimen 2.

Number of the Experiment.	Date.	Whistled, the Insect Shielded from the Air Currents.	Whistled, the Insect Not Shielded from the Air Currents.	Number of Times it Was Necessary to Whistle Before the Moth Responded.
1	June 6, 1913, 9:00 A.M.....	*Q*		6
2	" " "		*F*	2
3	" " "	*F*		5
4	" " "	*Q*		4
5	June 6, 1913, 10:00 A.M....		*F*	1
6	" " " ...	*F*		4
7	" " " ...	*Q*		3
8	" " " ...	*F*		2
9	June 6, 1913, 6:00 P.M.....	*F*		1
10	" " "	*Q*		3
11	" " "	*F*		2
12	" " "	*Q*		6
13	June 7, 1913, 10:00 A.M....	*F*		2
14	" " " ...		*F*	
15	" " " ...	*F*		4
16	" " " ...	*Q*		5
17	June 7, 1913, 11:00 A.M....	*F*		2
18	" " " ...	*QF*		4
19	" " " ...	*F*		4
20	" " " ...	*Q*		4
21	June 7, 1913, 6:00 P.M.....	*F*		3
22	" " "	*Q*		3
23	" " "	*F*		2
24	" " "	*Q*		8
25	June 8, 1913, 9:00 A.M.....	*N*		
26	" " "		*F*	1
27	" " "	*Q*		3
28	" " "	*F*		8
29	June 8, 1913, 11:00 A.M....	*F*		4
30	" " " ...	*Q*		6
31	" " " ...	*F*		4
32	June 8, 1913, 7:00 P.M.....	*F*		10
33	" " "	*Q*		6
34	" " "	*F*		2
35	" " "	*Q*		6
36	June 9, 1913, 9:00 A.M.....		*F*	2
37	" " "	*Q*		10
38	" " "	*F*		2
39	" " "	*Q*		10
40	June 9, 1913, 11:00 A.M....		*F*	2
41	" " " ...	*Q*		9
42	" " " ...	*F*		1
43	" " " ...	*Q*		11
44	June 9, 1913, 7:00 P.M.....	*Q*		6
45	" " "	*F*		1
46	" " "	*Q*		6
47	" " "	*F*		10

Table III.

Catocala unijuga. Specimen Number 3.

Number of the Experiment.	Date.	Whistled, the Insect Shielded from the Air Currents.	Whistled, the Insects Not Shielded from the Air Currents.	Number of Times it Was Necessary to Whistle Before the Response.
1	June 7, 1913, 9:00 A.M.	*N*		
2	“ “ “		*F*	1
3	“ “ “	*Q*		3
4	“ “ “	*F*		2
5	“ “ “	*Q*		10
6	June 7, 1913, 10:00 A.M. ...	*F*		2
7	“ “ “ ...	*Q*		6
8	“ “ “ ...	*F*		2
9	“ “ “ ...	*Q*		10
10	June 7, 1913, 7:00 P.M.	*F*		2
11	“ “ “	*Q*		10
12	“ “ “	*F*		4
13	“ “ “	*Q*		15
14	June 8, 1913, 9:00 A.M.	*F*		3
15	“ “ “	*Q*		6
16	“ “ “	*F*		4
17	“ “ “	*Q*		10
18	June 8, 1913, 10:00 A.M. ...	*N*		
19	“ “ “ ...	*Q*		10
20	“ “ “ ...	*F*		6
21	“ “ “ ...	*Q*		5
22	June 8, 1913, 10:00 P.M. ...	*F*		6
23	“ “ “ ...	*Q*		4
24	“ “ “ ...	*F*		4
25	“ “ “ ...	*Q*		10
26	June 9, 1913, 9:00 A.M.	*F*		4
27	“ “ “	*Q*		3
28	“ “ “	*F*		6
29	“ “ “	*Q*		10
30	June 9, 1913, 11:00 A.M. ...	*F*		6
31	“ “ “ ...	*Q*		10
32	“ “ “ ...	*F*		5
33	“ “ “ ...	*Q*		8
34	June 9, 1913, 6:00 P.M.	*F*		10
35	“ “ “	*Q*		2
36	“ “ “	*F*		4
37	“ “ “	*Q*		6
38	June 10, 1913, 9:00 A.M. ...	*Q*		1
39	“ “ “ ...	*N*		
40	“ “ “ ...	*Q*		6
41	“ “ “ ...	*F*		2
42	“ “ “ ...	*Q*		7
43	June 10, 1913, 11:00 A.M. ..	*N*		
44	“ “ “ ...	*Q*		3
45	“ “ “ ...	*F*		1
46	“ “ “ ...	*Q*		11
47	June 10, 1913, 6:00 P.M. ...	*N*		
48	“ “ “ ...	*F*		2
49	“ “ “ ...	*Q*		6
50	“ “ “ ...	*F*		1
51	“ “ “ ...	*Q*		10

but, in some cases, the air current was allowed to strike the moth. The results of those experiments are recorded in tables I.–III.

On the twelfth of June the three specimens, which, up to that time, had been confined in separate rooms, were marked and placed in the same room. At nine A.M. that day, on the first sound of the whistle, they all flew, one after another, as though the flight of the first had evoked the flight of the others. At ten o'clock, the whistling caused two to fly and the other to quiver. The one that quivered was about ten feet away. On whistling again all flew. At six P.M. the whistling caused all to fly.

To our way of thinking this series of experiments is very instructive. That each of these three specimens responded to the whistle on the twelfth of June is unequivocal; that they usually responded to the whistle by either flying or by quivering is also evident; but, it is equally certain that two out of the three specimens did not respond to the whistle at all the first time it was sounded and that the third specimen responded in a feeble manner. When the moths did not respond to the blowing of the whistle at the beginning of the experiment, the current of air produced by whistling was allowed to strike the moth; immediately it flew, and thereafter it would usually fly when the whistle was sounded. There were some exceptions to this; but, in the main it was true. This seems a hint that the moth responds to sounds that have a life significance.

Field Experiments.

These experiments were conducted in a small stretch of woods at Meramec Highlands, near St. Louis, Mo. Previous experience had taught us that these insects would not respond to loud sounds of low pitch. For that reason we used as the sound producing instrument a Galton whistle set to give a high shrill note. One of us would stand where the moth could be observed; but far enough away not to disturb it. Experience had taught us what would be a safe distance. The other, whistle in hand, would approach the tree on the opposite side to that on which the moth was resting. When this experimenter was near to the tree the whistle was held at about the level of the moth and sounded one or more times. In such a position it was absolutely impossible for the moth to see either the whistle or the experimenter. The

whistle was usually 180° from the moth; but occasionally it was placed ten to fifteen degrees away, but out of sight of the moth. In a few rare cases, for a special purpose, the whistle was blown in the presence of the moth. Whenever that was done it is indicated in the tables. The results of these experiments are recorded in Tables IV.–XI. The tables are self explanatory.

Table IV.

Responses of *Catocala flebilis* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	e^5	Flew.
2	1		Flew.
3	1		Flew.
4	1		Flew.
5	5		Flew.
6	3		Flew.
7	1		Flew.
8	1		Flew.
9	1		Flew.
10	1		Flew.
11	1		Moved its antenna, but did not fly.
12	1		Flew.

Table V.

Responses of *Catocala habilis* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	a^4	Flew.
2	1		Flew.
3	1		Flew.
4	1		Flew.
5	1		Flew.
6	1		Flew.

In the experiments recorded in this table (Table V.) the Galton whistle was held three feet from the tree on which the moth was resting.

Table VI.

Responses of *Catocala neogama* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	e^5	No response.
2	1		No response.
3	1	a^4	Flew (saw the whistle).
4	1	a^4	Flew.
5	1		Flew.

Table VII.

Responses of *Catocala piatrix* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	2	b^4	No response observed.
2	1		Flew.
3	1		Flew.
4	1		Moved its wings up and down
5	1		Ditto.
6	1		Flew.
7	1		No response observed.
8	1		Moved its wings up and down
9	1		Ditto.
10	1		Flew.
11	14		No response observed.
12	1		Moved its wing up and down.

Table VIII.

Responses of *Catocala relicta* var. *luctuosa* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	e^5	Made quivering movements with its wings.
2	1		Ditto.
3	1		Ditto.
4	1		Ditto.
5	1		Ditto.
6	1		Ditto.
7	1		Ditto.
8	1	a^4	Flew (It saw the whistle).
9	1		Whole body quivered.
10	1		Ditto
11	1		Ditto.
12	1		Ditto.
13	1		Ditto.
14	1		Ditto.
15	1		Ditto.
16	1		Ditto.
17	1		Ditto.
18	1		Ditto.
19	1		Ditto.
20	1		Ditto.
21	1		Ditto.
22	1		Ditto.
23	1		Moved antennæ gradually forward and then flew.
24	1		Body quivered.
25–35			Ditto.
36	1		Flew.
37	1		Whole body quivered.
38–43	1		Ditto.
44	1		Moved its antennæ four times and then flew.

Table IX.

Responses of *Catocala robinsoni* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1		Flew.
2	1		Flew.
3	1		Flew.
4	1		Flew.

Table X.

Responses of *Catocala vidua* to Sound.

Number of the Experiment.	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	a^4	No response observed.
2	1		Flew.
3	1		Flew.
4	1		Flew.
5	1		Flew.
6	1		No response observed.
7	1		Ditto.
8	1		Ditto.
9	1		Ditto.
10	1		Ditto.
11	1		Ditto.
12	1		Flew (It saw the whistle).
13	1		No response observed.
14	1		Flew.
15	1		Flew.
16	1		No response observed.
17	1		Flew.
18	1		No response observed.
19	1		Flew.
20	4		Flew.

Table XI.

Responses of *Catocala vidua*, Specimen Number 2, to Sound.

Number of the Experiment	Number of Times the Whistle Was Sounded.	Pitch of the Whistle.	Kind of Response.
1	1	a^4	Moved its antennæ.
2	1		Flew.
3	1		Flew.
4	19		Flew, but not until after the nineteenth whistle.
5	1		Flew.
6	4		No response noticed.
7	4		No response noted.
8	1		Flew (Saw the whistle).

In June, 1914, we made an attempt to see if, in the field, moths could be trained to respond to sounds to which they do not normally respond. We knew that this can be done in the laboratory. Our experience the year before had informed us that most Catocalæ do not respond to sounds of a low pitch. We selected an organ pipe giving 256 vibrations per second. This was sounded several times and if the moth did not respond it was sounded again and simultaneously one of us touched the moth with a brush. We then followed the moth to its next resting place and sounded it again, and if necessary, repeated it over and over.

For these experiments we used; *C. amica*, *C. epione*, *C. neogamma*, *C. ilia*, and *C. innubens*. With *innubens* and *epione* all results were negative. We found two specimens of *ilia* which responded to the sound of the pipe before they had been touched in any manner and one that did not so respond. This response from *ilia* was unexpected, but it militated against using it for these experiments. We succeeded in inducing one specimen of *amica* to respond to the pitch; but failed completely with two others. We experimented with five specimens of *C. neogama*, all males. We induced three individuals of *neogama* to respond to the sound of the organ pipe; but failed with two others. Although the cases in which we succeeded in inducing the moths to respond to sounds to which they do not usually react are few, the fact that we did succeed in a few cases supports our contention that these insects respond only to sounds that have a life significance.

Conclusions.

1. Our field experiments demonstrate that several different species of *Catocala* moths respond to certain high pitched notes of the Galton whistle; but that they usually do not respond to sounds of low pitch, such as the rumbling of trains, etc.

2. Most specimens responded to those high notes by flying to a nearby tree; but some, and this was especially true of *Catocala relicta*, responded by making quivering movements with its wings.

3. The degree of responsiveness was not the same in all species. Among the least responsive were *C. vidua* and *C. neogama;* at the other extreme were *C. flebilis*, *C. habilis*, and *C. robinsoni.*

4. We do not consider the failure of these moths to respond to certain sounds of low pitch a proof that they do not hear such sounds; indeed, we are inclined to believe that these creatures respond only to such sounds as have a life significance. Three things render this last assumption probable: (1) The fact that *C. unijuga*, which at first did not respond to whistling, did so readily after once a blast of air had been allowed to strike her body simultaneously with the sounding of the whistle; (2) that most of the natural enemies of these moths produce high pitched sounds and trains, and brass bands and other producers of low pitched or coarse sounds do not directly affect the survival of these moths; and (3) by carefully conducted field experiments, we were able to induce three specimens of *C. neogama* to respond to sounds to which the species does not usually react.

References.

The following list is not intended to be a complete bibliography of the sense of hearing of insects. It contains only such articles as have been referred to in the body of this paper. An effort has been made, however, to include all papers treating of experiments upon the auditory powers of the Lepidoptera. If any such have been omitted, it is because they have escaped our notice.

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